Table 4.8. Radionuclides Emitted to the Atmosphere at the Hanford Site, 2001 (Poston et al. 2002)

Radionuclide	Half-Life in Years	Emission, Ci [(a)]				
		100 Areas	200 East Area	200 West Area	300 Area	400 Area
Tritium (as HT)[(b)]	12.3 yr	NM[(c)]	NM	NM	8.9E+01	NM
Tritium (as HTO)[(b)]	12.3 yr	NM	NM	NM	2.4E+02	3.1E-01
Cobalt-60	5.3 yr	3.0E-08	ND[(d)]	ND	ND	NM
Strontium-90	29.1 yr	9.0E-06	1.2E-04[(e)]	1.4E-04[(e)]	2.8E-05[(e)]	NM
Technetium-99	2.13×10^5 yr	NM	NM	NM	ND	NM
Antimony-125	2.77 yr	ND	ND	ND	ND	NM
Iodine-129	1.6×10^7 yr	NM	8.4E-04	NM	NM	NM
Cesium-137	30 yr	2.1E-05	1.2E-04	5.5E-05	3.7E-06	7.5E-06[(f)]
Uranium-234	2.4×10^5 yr	NM	NM	NM	1.5E-10	NM
Uranium-238	4.5×10^9 yr	NM	NM	NM	3.3E-11	NM
Plutonium-238	87.7 yr	1.5E-07	4.4E-08	4.5E-06	7.7E-09	NM
Plutonium-239, 240	2.4×10^4 yr	1.2E-06	2.1E-06[(g)]	2.6E-04[(g)]	1.9E-07[(g)]	6.9E-07[(g)]
Plutonium-241	14.4 yr	1.2E-05	3.1E-06	1.4E-04	NM	NM
Americium-241	432 yr	9.5E-07	2.6E-06	4.2E-05	2.5E-08	NM
Americium-243	7380 yr	NM	NM	NM	ND	NM

(a) 1 Ci = 3.7 E+10 Bq;
(b) HTO = tritiated water vapor; HT = elemental tritium.
(c) NM = not measured;
(d) ND = not detected (i.e., either the radionuclide was not detected in any sample during the year or the average of all the measurements for that given radionuclide or type of radioactivity made during the year was below background levels).
(e) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be strontium-90 for dose calculations.
(f) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be plutonium-239/240 for dose calculations.
(g) Analyses were conducted for gross alpha activity, but none was detected. If detected, it would have been assumed to be plutonium-239/240 for dose calculations.

4.4 Geologic Resources

Geologic considerations for the Hanford Site include topography and geomorphology, stratigraphy, soil characteristics, and seismicity. This section, which provides an overview of the Hanford Site subsurface environment, focuses primarily on the 200 Area Plateau, located in the center of the site.

4.4.1 Topography and Geomorphology

The sites associated with the Hanford Solid Waste Program are located on a broad flat area of the Hanford Site commonly referred to as the Central Plateau. The Central Plateau is within the Pasco Basin, a topographic, structural depression in the southwest corner of the Columbia Basin physiographic subprovince. This subprovince is characterized by generally low-relief hills with deeply carved river drainage. The elevation of the Central Plateau is approximately 200 m (650 ft) to 230 m (750 ft) above mean sea level. The Plateau decreases in elevation to the north, northwest, and east toward the Columbia River. Plateau escarpments have elevation changes of 15 m (50 ft) to 30 m (100 ft). The Pasco Basin is an area of generally low relief ranging from 120 m (390 ft) above mean sea level at the Columbia River level, to 230 m (750 ft) above mean sea level in the 200 East Area. The Pasco Basin is bounded on the north by the Saddle Mountains; on the west by Umtanum Ridge, Yakima Ridge, and the Rattlesnake Hills; on the south by Rattlesnake Mountain and the Rattlesnake Hills; and on the east by the Palouse Slope. The Pasco Basin is shown in Figure 4.9.

Surface topography at the Hanford Site is the result of the uplift of anticlinal ridges, Pleistocene cataclysmic flooding, Holocene eolian activity, and landslides (Delaney et al. 1991). Uplift of the ridges began in the Miocene Epoch (24 to 5 million years ago), concurrent with the eruption of the flood basalts. Cataclysmic flooding occurred when glacial ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington State.

Much of the landscape in the path of the floodwater was stripped of sediments and basalt bedrock was scoured, forming scabland topography (elevated areas underlain by flat-lying basalt flows that generally exhibit deep, dry channels scoured into the surface). The last major flood occurred approximately 13,000 years ago during the late Pleistocene Epoch. Since then, winds have locally reworked the flood sediments, depositing dune sands in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Anchoring vegetation has stabilized many sand dunes. Where human activity or natural events have disturbed this vegetation, dunes have been reactivated. For example, dunes have been reactivated by the removal of vegetation as a consequence of a large wildfire that occurred on the Hanford site in July 2000.

The 200 Areas are situated between the Gable Mountain anticline and the Cold Creek syncline. The Gable Mountain anticline is of particular importance to the groundwater flow. Portions of this anticline have been uplifted to a point where basalt is above the current water table. These basalts have a low hydraulic conductivity and act as a barrier to horizontal groundwater flow in the unconfined aquifer.

4.4.2 Stratigraphy

The stratigraphy of the Hanford Site consists of Miocene-age and younger rocks. Older Cenozoic sedimentary and volcaniclastic rocks underlying the Miocene rocks are not exposed at the surface. Figure 4.10 summarizes the Hanford Site stratigraphy. A generalized west to east cross-section depicting site structure and topography is shown as Figure 4.11.

Over 100 basalt flows of the Columbia River Basalt Group, with a total thickness exceeding 3000 m (10,000 ft), lie beneath the Hanford Site. Interbedded between many of these basalt flows are sedimentary rocks of the Ellensburg Formation, a series of sand, gravel, or silt layers that were deposited by the ancestral Columbia River system. Sediments up to 230 m (750 ft) thick overlie the Columbia River Basalt Group, and include the Ringold and Hanford formations. Thin, laterally discontinuous

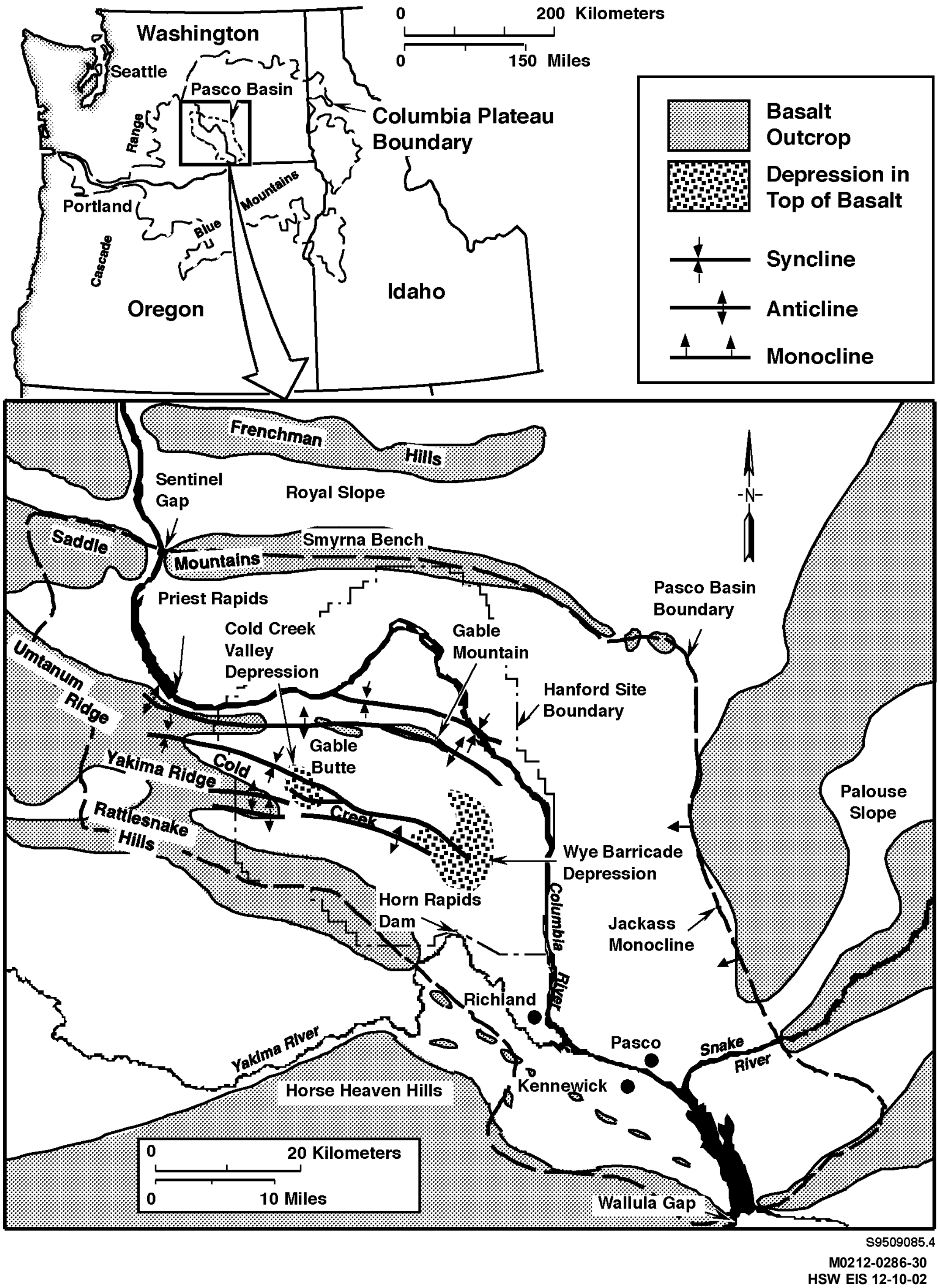

Figure 4.9. Geographic Setting and General Structural Geology of the Pasco Basin and Hanford Site (Bergstrom et al. 1983)

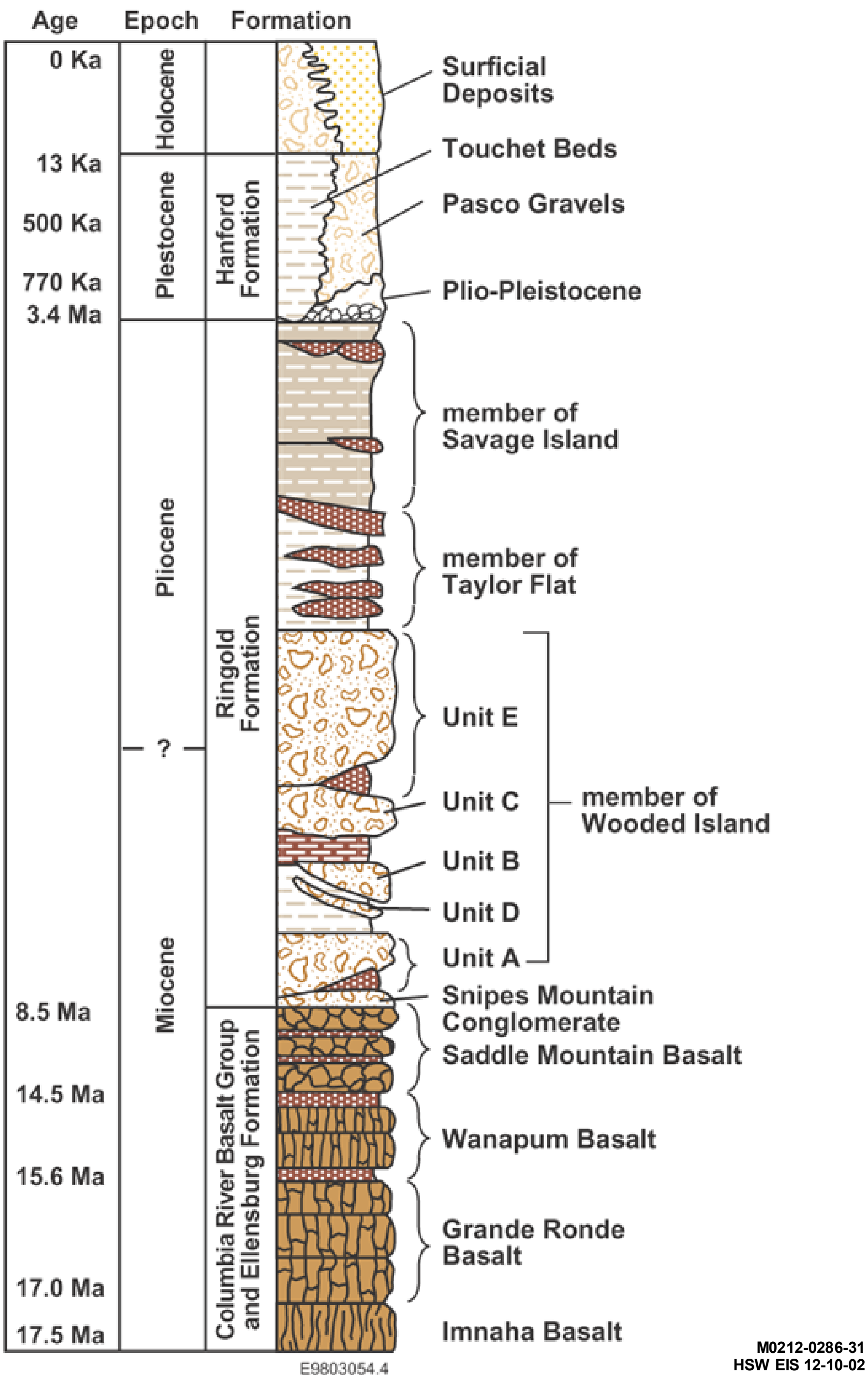

Figure 4.10. Stratigraphic Column for the Hanford Site (Reidel et al. 1992; Ka = thousand years; Ma = million years)

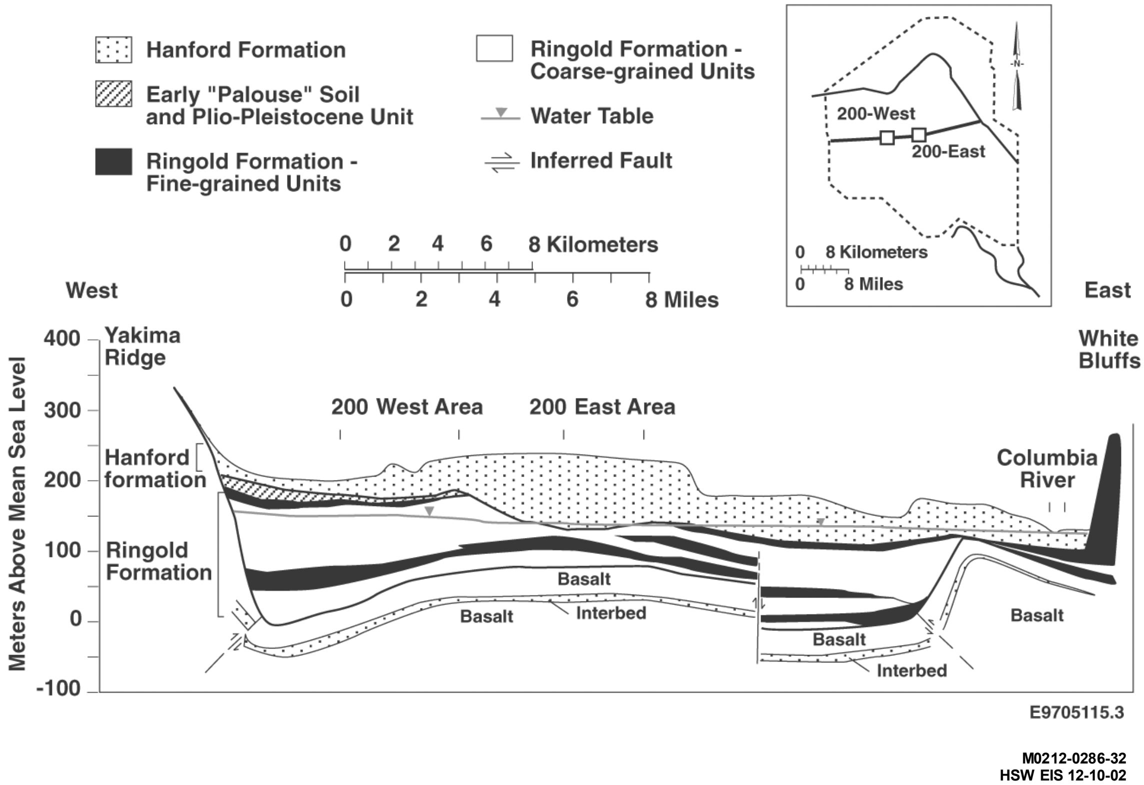

Figure 4.11. Generalized West to East Cross-Section of the Hanford Site Structure and Topography (DOE-RL 1999)

sedimentary deposits, referred to as the Plio-Pleistocene unit, pre-Missoula gravels, and early Palouse soil, locally separate the Ringold Formation from the overlying Hanford formation.

The Ringold Formation consists of siltstones, sandstones, and conglomerates deposited by the ancestral Columbia River system between 8 and 3 million years ago. The Ringold Formation reaches 180 m (600 ft) in thickness in the Cold Creek syncline south of the 200 West Area but thins and pinches out to the north. It is subdivided into five gravel layers referred to as Units A, B, C, D, and E that are separated by finer-grained units, including the lower mud (Figure 4.10).

The Hanford formation was deposited between 2 million years and 10,000 years ago by cataclysmic flooding from glacial Lake Missoula. The Hanford formation consists of pebble to boulder gravel, fine to coarse-grained sand, and silt, and is thickest (up to 65 m [210 ft]) under the 200 Areas. Gravel dominates the Hanford formation in the northern part of the area, while sand-dominated material is found most commonly in the central to southern parts. Holocene surficial deposits consisting of silt, sand, and gravel form a thin (less than 10-m [33-ft]) surface layer across much of the Hanford Site. Eolian (wind) and alluvial processes deposited these surficial materials.

The geology in the 200 West Area is notably different from the 200 East Area, considering a distance of only 6 km (4 mi) separates them. One of the most complete suprabasalt stratigraphic sections on the Hanford Site containing most Ringold units, the Plio-Pleistocene unit, early Palouse soil, and the Hanford formation, is present in the 200 West Area.

In the 200 East Area, most of the Ringold Formation units are present in the southern part but have been eroded in a complex pattern to the north. On the north side of the 200 East Area, the Hanford formation rests directly on the basalt, and no Ringold sediments are present. Erosion by the ancestral Columbia River and catastrophic flooding are believed to have removed the Ringold Formation from this area. A unit of questionable origin locally overlies basalt within the B-BX-BY Waste Management Area (Schalla et al. 2000). This unit, referred to informally as H/PP deposits, may be equivalent or partially equivalent to the Plio-Pleistocene unit or it may represent the earliest ice-age flood deposits overlain by a locally thick sequence of fine-grained non-flood deposits.

4.4.3 Soils

Hajek (1966) describes 15 different soil types on the Hanford Site, varying from sand to silty and sandy loam. These soils are shown in Figure 4.12 and briefly described in Table 4.9.

The majority of the 200 West Area soils are Rupert Sand; the remaining third is Burbank Loamy Sand. The 200 East Area soils are composed of Ephrata Sandy Loam, Rupert Sand, and Burbank Loamy Sand.

4.4.4 Seismicity

The Hanford Site lies in an area of relatively low seismic activity. Figure 4.13 shows the locations of known earthquakes that occurred in the Columbia Plateau between 1850 and 1969 with a Modified Mercalli Intensity (MMI) of V or more and at Richter magnitude 4.0 or more. The largest earthquake that may have occurred in the eastern Washington area shown in Figure 4.13 happened in 1872, with MMI IX and estimated magnitude near 7.0, but its location has been variously estimated from Wenatchee to British Columbia. Figure 4.14 shows the locations of all earthquakes that occurred from 1969 to 2000 at Richter magnitudes of 3.0 or more. The largest known earthquake in the Columbia Plateau occurred in 1936 near Milton-Freewater, Oregon. This earthquake had a Richter magnitude of approximately 6.0 and a maximum MMI of VII, and was followed by a number of aftershocks indicating a northeast-trending fault plane. Other earthquakes with Richter magnitudes ≥ 5 or MMI of VI occurred along the boundaries of the Columbia Plateau in a cluster near Lake Chelan in 1872 extending into the northern Cascade Range, in northern Idaho and Washington, and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the Columbia Plateau, including one event in the Milton-Freewater, Oregon, region in 1921; one near Yakima, Washington, in 1892; and one near Umatilla, Oregon, in 1893. In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events were magnitude 4.4 and intensity V, and were located north of the Hanford Site near Othello.

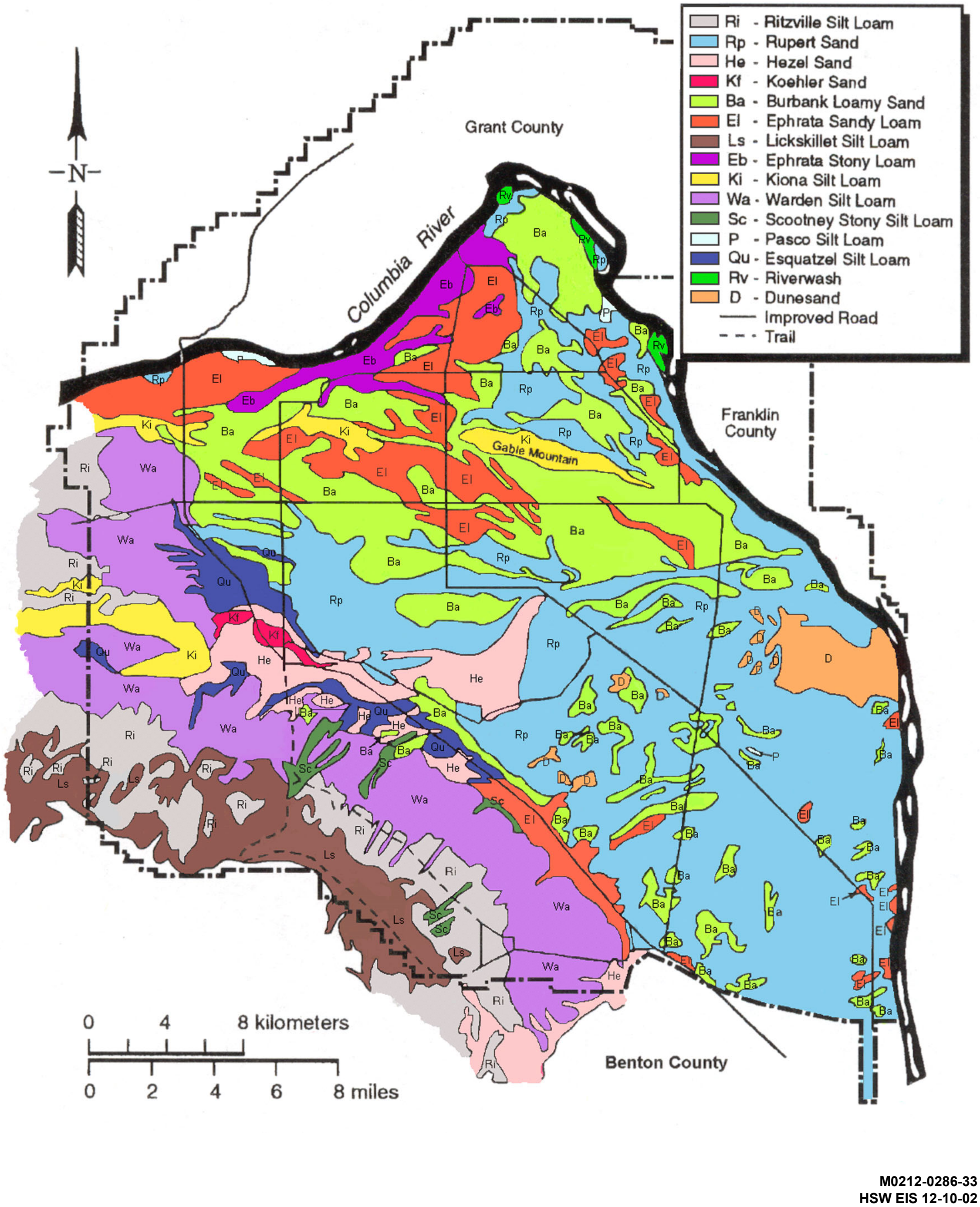

Figure 4.12. Soil Map of the Hanford Site (after Hajak 1966). (See Table 4.9 for description of soil types.)

Table 4.9. Soil Types on the Hanford Site (after Hajek 1966)

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically greater than 150 cm (60 in.) deep, but bedrock may occur between 75 and 150 cm (30 and 60 in.).
Rupert Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to grayish-brown coarse sand grading to dark grayish-brown at 90 cm (35 in.). Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky terraces and dune-like ridges.
Hezel Sand (He)	Similar to Rupert sands; however, laminated grayish-brown strongly calcareous silt loam subsoil is usually encountered within 100 cm (39 in.) of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in the sand mantles a lime-silica cemented Hardpan layer. Very dark grayish-brown surface layer is somewhat darker than Rupert. Calcareous subsoil is usually dark grayish-brown at about 45 cm (18 in.).
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 40 cm (16 in.) thick but can be 75 cm (30 in.) thick. Gravel content of subsoil ranges from 20 percent to 80 percent.
Ephrata Sandy Loam (El)	Surface is dark colored and subsoil is dark grayish-brown medium-textured soil underlain by gravelly material that may continue for many feet. Level topography.
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes greater than 765 m (2509 ft) elevation. Similar to Kiona series except the surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large hummocky ridges are made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish-brown and about 10 cm (4 in.) thick. Dark-brown subsoil contains basalt fragments 30 cm (12 in.) and larger in diameter. Many basalt fragments are found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.
Warden Silt Loam (Wa)	Dark grayish-brown soil with a surface layer usually 23 cm (9 in.) thick. Silt loam subsoil becomes strongly calcareous at about 50 cm (20 in.) and becomes lighter colored. Granitic boulders are found in many areas. Usually greater than 150 cm (60 in.) deep.

Table 4.9. (contd)

Name (symbol)	Description
Scootney Stony Silt Loam (Sc)	Developed along the north slope of Rattlesnake Hills; usually confined to floors of narrow draws or small fan-shaped areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish-brown grading to grayish-brown in the subsoil.
Pasco Silt Loam (P)	Poorly drained very dark grayish-brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on the Hanford Site, located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and adjacent land.
Dunesand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind. Are either actively shifted or so recently fixed or stabilized that no soil horizons have developed.

In addition, earthquake swarms of small magnitudes that are not associated with mapped faults occur on and around the Hanford Site. The region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site. The frequency of earthquakes in a swarm tends to gradually increase and decay with no one outstanding large event within the sequence. Roughly 90 percent of the earthquakes in swarms have Richter magnitudes of 2 or less. These earthquake swarms generally occur at shallow depths, with 75 percent of the events located at depths <4 km (<2.5 mi). Each earthquake swarm typically lasts several weeks to months, consists of several to 100 or more earthquakes, and the locations are clustered in an area 5 to 10 km (3 to 6.2 mi) in lateral dimension.

Estimates for the earthquake potential of structures and zones in the central Columbia Plateau have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System (now Energy Northwest) Columbia Generating Station (formerly WNP-2), the U.S. Nuclear Regulatory Commission (NRC) concluded that four earthquake sources should be considered for seismic design: the Rattlesnake-Wallula alignment, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area (NRC 1982).

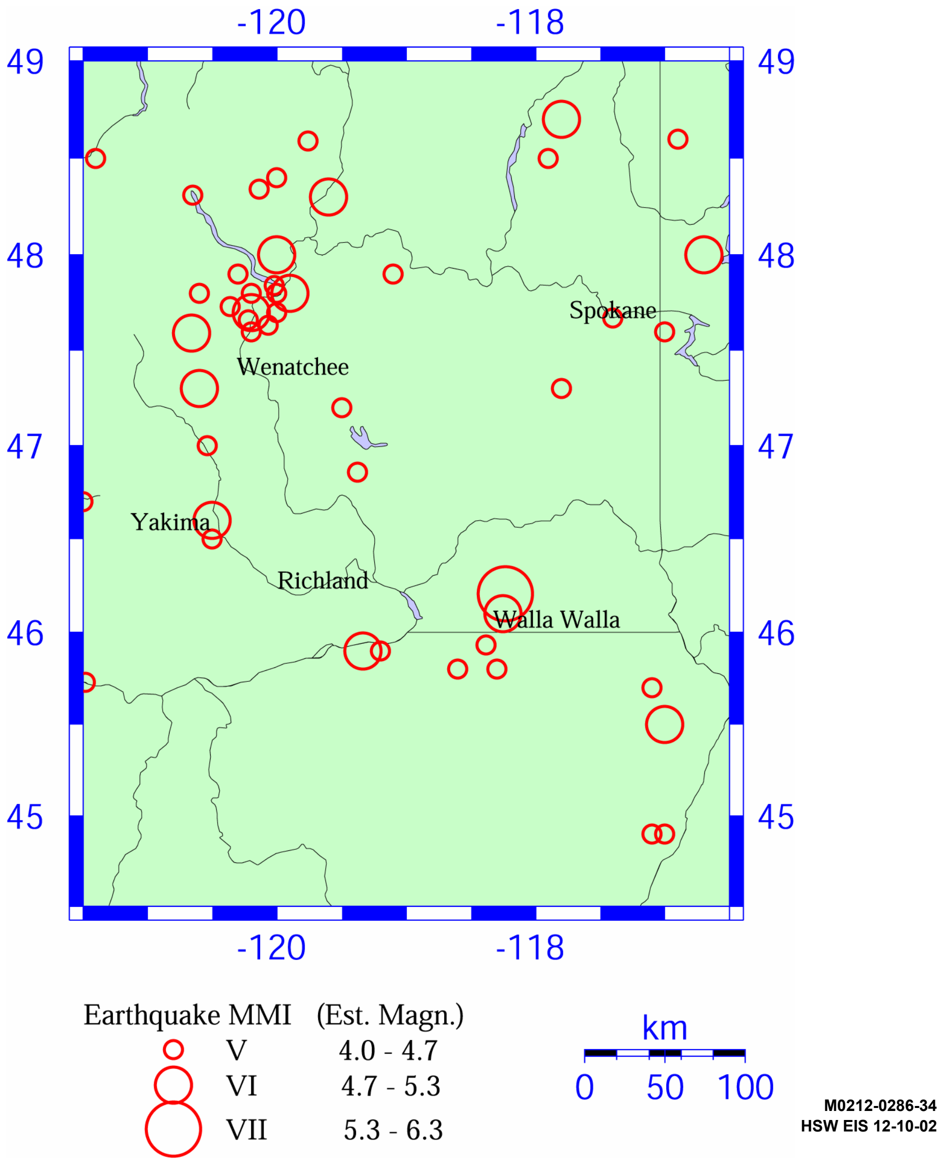

Figure 4.13. Historical Seismicity of the Columbia Plateau and Surrounding Areas. All earthquakes between 1850 and March 20, 1969, with a Modified Mercalli Intensity of V or larger or a Richter magnitude of 4.0 or larger, are shown (Rohay 1989). The magnitude ranges correspond to the original intensity estimated historically. Symbol sizes are only approximately related to those used in Figure 4.14. The uncertain location of the 1872 earthquake is not shown.

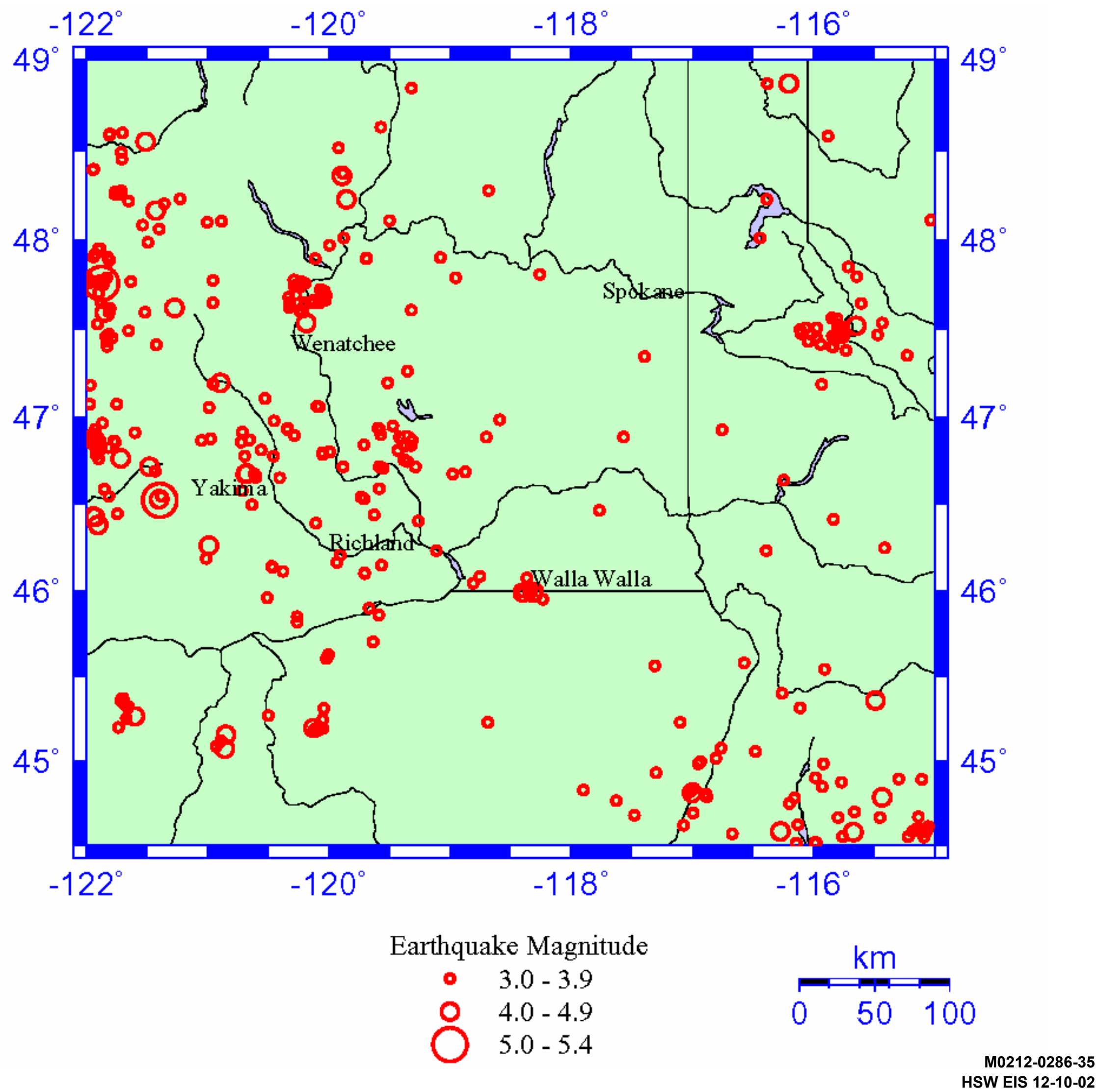

Figure 4.14. Seismicity of the Columbia Plateau and Surrounding Areas as Measured by Seismographs. All earthquakes from 3/20/1969 to 12/31/2000 with Richter magnitude 3 or larger are shown. Data sources: Council of the National Seismic System (CNSS 2001), University of Washington Geophysics Program (UWGP 2001).

For the Rattlesnake-Wallula alignment, which passes along the southwest boundary of the Hanford Site, the NRC estimated a maximum Richter magnitude of 6.5; for Gable Mountain, an east-west structure that passes through the northern portion of the Hanford Site, a maximum Richter magnitude of 5.0 was estimated. These estimates were based upon the inferred sense of slip, the fault length, and the fault area. The floating earthquake for the tectonic province was developed from the largest event located in the Columbia Plateau, the Richter magnitude 5.75 Milton-Freewater earthquake. The maximum swarm earthquake for the purpose of Columbia Generating Station seismic design was a Richter magnitude 4.0 event, based on the maximum swarm earthquake in 1973. (The NRC concluded the actual magnitude of this event was smaller than estimated previously.)

Probabilistic seismic hazard analyses have been used to determine the seismic ground motions expected from multiple earthquake sources, and these are used to design or evaluate facilities on the Hanford Site. The most recent Hanford Site-specific hazard analysis (Tallman 1994, 1996) estimated that 0.10 g (1 g is the acceleration of gravity) horizontal acceleration would be experienced on average every 500 yr (or with a 10 percent chance every 50 yr). This study also estimated that 0.2 g would be experienced on average every 2500 yr (or with a 2 percent chance in 50 yr). These estimates are in approximate agreement with the results of national seismic hazard maps produced by the U.S. Geological Survey (Frankel et al. 1996).

The Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) operate a 40-station seismic monitoring network in eastern Washington, which has been used to determine the locations and magnitudes of earthquakes since 1969. In addition, PNNL operates a network of five strong motion accelerometers near Hanford facilities to measure ground motion levels from larger earthquakes (Hartshorn et al. 2001).

4.5 Hydrology

Hydrology considerations at the Hanford Site include surface water, the vadose zone, and groundwater. The vadose zone is the unsaturated or partially saturated region between ground surface and the saturated zone. Water in the vadose zone is called soil moisture. Groundwater refers to water within the saturated zone. Permeable saturated units in the subsurface are called aquifers.

4.5.1 Surface Water

Surface water at Hanford includes the Columbia River, Columbia riverbank seepage, springs, and ponds. Intermittent surface streams, such as Cold Creek, may also contain water after large precipitation or snowmelt events. In addition, the Yakima River flows near a short section of the southern boundary of the Hanford Site (Figure 4.15).

4.5.1.1 Columbia River

In terms of total flow, the Columbia River is the second largest river in the contiguous United States and is the dominant surface-water body on the Hanford Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River.

Originating in the mountains of eastern British Columbia, Canada, the Columbia River drains an area of about 680,000 km^2 (260,000 mi^2) en route to the Pacific Ocean. The primary uses of the Columbia River include the production of hydroelectric power, irrigation of cropland in the Columbia Basin, and transportation of materials by barge. Many communities located on the Columbia River rely on the river as their source of drinking water (see Section 4.8.9). The Columbia River is also used as a source of drinking water and industrial water for several Hanford Site facilities (Dirkes 1993). In addition, the Columbia River is used extensively for recreation that includes fishing, bird hunting, boating, sail boarding, water skiing, diving, and swimming.